THE ANALYSIS OF HEART SOUNDS BASED ON LINEAR AND HIGH ORDER STATISTICAL METHODS

Burhan Ergen, Yetkin Tatar
Department of Computer Engineering, Firat University, Elazig, Turkey

Abstract- **This paper investigates the applicability of high order statistical autoregressive (AR-HOS) modeling method in analyzing biomedical signals. The autoregressive (AR) method using linear prediction and AR-HOS method using cumulants are applied on normal and pathological heart sound signals. It is found that the AR-HOS modeling a signal produce more accurate and higher resolution spectrum than AR modeling.**
***Keywords*- Heart sound, signal modeling, high order statistic.**

I. INTRODUCTION

Audible heart sounds carry a lot of valuable information about the condition of the patient's heart. The spectral analysis of heart sounds give more useful information in detecting of heart disease than listening.

Previous studies have indicated that traditional FFT analysis may not suitable to distinguish normal patient from abnormal patient due to limits on resolution [1]. It also may not produce accurate frequency spectra because the low-level heart sound are contaminated with considerable background noise [2], [3]. However the averaging processes in traditional method improve the estimate of the power spectra, it doesn't reduce the influence of noise.

Since the application of parametric modeling methods to signal identification problems can result in a better estimation of spectral features, model-based methods have been used to study and classify heart sounds [4]-[8]. A number of studies have shown that parametric modeling methods can be used to detect sound associated with coronary stenosis [1], [3], [8], [7]. The parametric modeling methods in these studies generally use linear prediction algorithm methods, such as Levinson-Durbin or Yule-Walker algorithms based on autocorrelation matrix, to find out the autoregressive (AR) coefficient modeling the original signal.

The application of the parametric modeling using autocorrelation matrix inherently assumes that the modeled signal is linear. In recent years, it has been suggested that heart dynamics may be nonlinear [8]. If this proposal is true, it may be used autoregressive higher order statistical (AR-HOS) methods using cumulants to model heart sound. To examine the exact feature and extract more information involve in phonocardiographic signals, this contribution proposes the higher-order spectra for analysis of heart sounds. AR-HOS modeling can reveal more information than power spectrum can. The purpose of this contribution is to discuss AR and AR-HOS modeling of heart sounds on common known disease.

II. METHODOLOGY

A. AR Methods

The AR model known as all-pole method is the most widely used modeling method to estimate the power spectral density (PSD) function associated with some biological signals [9]. Each sample of signal can be expressed as a linear combination of previous samples and an error signal. The error signal assumed to be independent of the previous samples [1], [4].

$$y(n) = -\sum_{p=1}^{M} a_p y(n-p) + e(n) \tag{1}$$

where y(n) represents the signal to be modeled, a_p represent the AR coefficient of the AR process at the p th stage, $e(n)$ represents the estimated error signal, and M represents the AR model order [12].

The AR estimation of the power spectral density function is given by

$$S_{yy}(w) = \frac{\sigma^2}{\left|1 + \sum_{p=1}^{M} a_p e^{jw_p}\right|^2} \tag{2}$$

where σ^2 is the noise variance, and w is the frequency.

The estimation of the PSD of the AR method was carried out by using Yule-Walker method [9].

B. AR-HOS Methods

The AR-HOS methods also known as bispectral AR modeling based on third-order statistic (AR-TOS). The equation describing the autoregressive model is:

$$y_n = \sum_{i=1}^{p} a y_{n-i} = w_n, \qquad a_0 = 1 \tag{3}$$

where, y_n represents a p^{th} order AR process of N samples $(n = 0,1...N-1)$, a_i are the coefficient of the AR model, and w_n are i.i.d., non-Gaussian, third order stationary, zero-mean, with $E\{w_n{}^3\} = \beta \neq 0$ and y_n independent of w_l for $n < l$. Since w_n third-order stationary, y_n is also third-order

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle The Analysis of Heart Sounds Based on Linear and High Order Statistical Methods	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Department of Computer Engineering Firat University Elazig, Turkey	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 3	

stationary, assuming it is a stable AR model. For the model of (3), it can be written the cumulant-based ‘normal equations’:

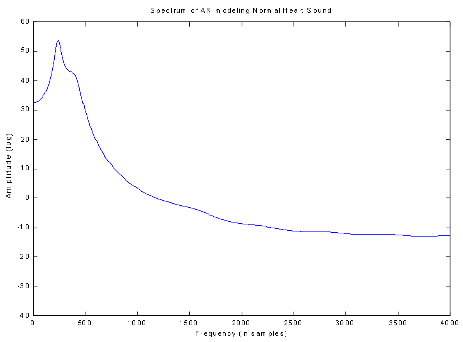
$$\sum_{i=0}^{p} a_i R(\tau_1 - i, \tau_2) = 0, \tau_1 = 1,\ldots, p \,\&\, \tau_2 = -p,\ldots,0 \qquad (4)$$

where, $R(\tau_1, \tau_2)$ is the third order cumulant sequence (TOS) of the AR process. In practice, it is used sample of the cumulants. (4) yields consistent estimates of the AR parameters maintaining the ortogonality of the prediction sequence to an instrumental process derived from the data [10].

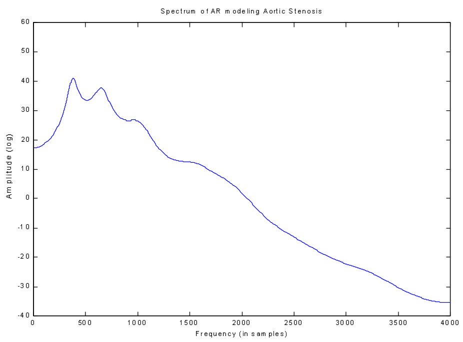
The AR estimation of the power spectral density function is given by

$$\hat{H}(w) = \frac{1}{1 + \sum_{i=1}^{p} \hat{a}_i e^{-jwi}}, \qquad |w| \le \pi \qquad (5)$$

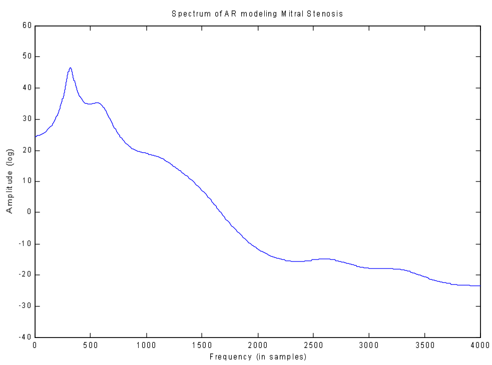
where $\hat{a}_i$ is estimated AR coefficients, and w is frequency [11].



a)

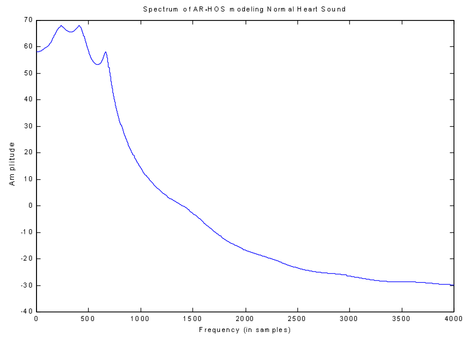


b)

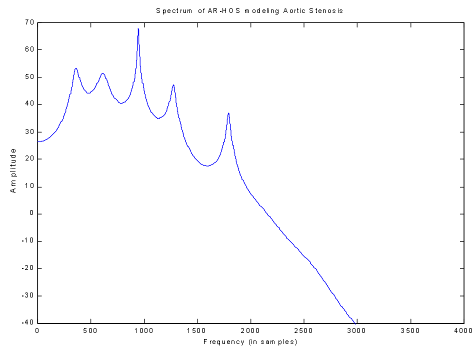


c)

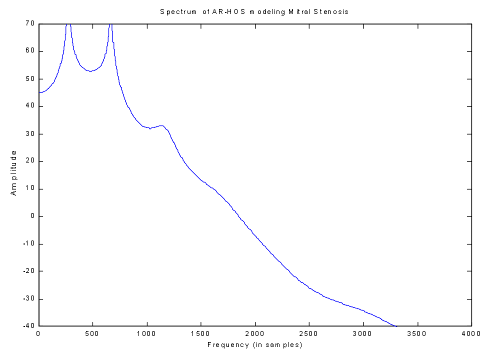
Fig. 1. The AR spectrums of the heart sounds: (a)Normal heart sound. (b) Mitral Stenosis. (c) Aortic Stenosis.



a)



b)



c)

Fig. 2. The AR-HOS spectrums of the heart sounds: (a) Normal heart sound. (b) Mitral Stenosis. (c) Aortic Stenosis.

C. Data Acquisition

The database used to evaluate the methods is from a compact disk containing a selection of phonocardiogram (PCG) of normal and pathalogical heart sound and murmers.[1] The three of these PCG's were chosen because of characteristic of important clinical conditions and relatively low background noise level. The digitized sounds with 16 resolution at a sampling frequency 44.1kHz. was transferred into MATLAB environment to apply AR and AR-HOS signal modeling techniques. Since heart sounds don't contain significant in high frequency, the signals resampled at 1/20 rate to eliminate redundant data in order to decrease computational time in MATLAB.

III. RESULTS

Fig.1. represents the AR spectrums of the heart sounds having 15 coefficients. Since the application Akaike criterion demonstrated that between 5 and 15 AR coefficients are required to describe heart sound signals, the number of AR coefficient has chosen as 15 [3]. When Fig.2. is examined, it is observed that the diseased heart sound carry extra energy in high frequency relatively the normal heart sound.

Fig.2. represents the AR-HOS spectrums of the same sounds. In this figure, the features of carrying extra energy in high frequency again. The AR-HOS spectrums of the normal and pathological heart sound also shows more evident peaks than AR spectrums.

The results indicate that high order statistic is more applicable to biological signals.

IV. DISCUSSION

When we have applied the methods to all of the sounds in the database, we have reached the same result that AR-HOS modeling gives higher resolution in the spectrums than AR modeling with the same coefficient number. When the number of AR and AR-HOS coefficient reduced to 5 or 10, it was observed that the difference of resolution between two parametric modeling is kept on.

However, the AR-HOS modeling provide higher resolution, its algorithms to estimate the coefficient has more computational complexity.

V. CONLUSION

In this study, two advanced spectral methods have been applied to normal and pathological heart sounds to identify distinguishing features. Results showed that AR-HOS model is more capable of separating the normal patient from abnormal patient. The methods in this study are AR method based on linear prediction and AR-HOS method based on third order cumulants in high order statistical analysis.

Since the coefficients in parametric modeling methods are used in classification problems, the coefficients obtaining from AR-HOS modeling will give better result.

Consequently, we propose AR-HOS modeling in examination of heart sounds. Since produce more resolution result, it should be used in features extraction in classification operations such as neural networks.

[1] Heart sound and murmurs recorded by Morton E. Tavel, M. D., Professor of Medicine, Indiana University, School of Medicine and consulting cardiologist with Northside Cardiology Inc., Indianapolis, USA.

REFERENCES

[1] M.Akay, J.L.Semlow, W. Welkowitz, M. D. Bauser, and J. B. Kostis, "Noninvasive Detection of Coronary Stenoses Before and After Angioplasty Using Methods", IEEE Trans. Biomed. Eng. Vol.37. pp. 1095-1104, Nov. 1990.

[2] M.Akay, J. L. Semlow, W. Welkowitz, M. D. Bauser, and J. B. Kostis, "Detection of Coronary Occlusion Using Autoregressive Modleing of Diastolic Heart Sounds" IEEE Trans. Biomed. Eng. Vol.37. pp. 336-373, Apr. 1990.

[3] V. Padmanabhan, J. L. Semmlow, and W. Welkowitz, "Accelerometer type Cardiac Transducer for Detection of Low-Level Heart Sounds", IEEE Trans. Biomed. Eng. Vol.40. pp. 21-28, Jan. 1993.

[4] Y. M. Akay, M. Akay, W. Welkowitz, J. L. Semlow, and B. Kostis, "Noninvasive Acoustical Detection of Coronary Disease: A Comparative Study of Signal Processing Methods" IEEE Trans. Biomed. Eng. Vol.40. pp. 571-578, Jun. 1993.

[5] M.Akay, J. L. Semlow, W. Welkowitz, J. Kostis, "Parametric Modeling of Diastolic Heart Sounds Before and After Angioplasty" IEEE Eng. In Med.&Bio. Soc. 11 th Ann. Int. Conf. 1989.

[6] D. J. Chistini, F. M. Bennett, K. R. Lutchen, H. M. Ahmed, J. M. Hausdroff, and N. Oriol, "Application of Linear and Nonlinear Time Series Modeling to Heart Rate Dynamics Analysis" IEEE Trans. Biomed. Eng. Vol 42 pp. 411-415, Apr. 1995.

[7] Y. M. Akay, M. Akay, W. Welkowitz, J. L. Semlow, and B. Kostis, "A Comparative Study of Advanced Signal Processing Techniques for Detection of Coronary Artery Disease", Ann. Int. Conf. of the IEEE Eng. in Med. and Bio. Soc. Vol.13. No.5, 1995.

[8] Y. M. Akay, M. Akay, W. Welkowitz, J. L. Semlow, and B. Kostis, "Noninvasive Detection of Coronary Artery Disease Using Neural Networks" Ann. Int. Conf. of the IEEE Eng. in Med. and Bio. Soc. Vol.13.1991.

[9] S. M. Kay, Modern Spectral Estimation: Theory and Application, Englewood Cliffs, NJ. Prenttice Hall, 1988.

[10] A. Swami, J. M. Mendel, C. L. Nikias, High Order Spectral Analysis Toobox, The MathWorks, USA, 1995.

[11] A. Galleo and D. P. Ruiz, "AR-modelling bispectrum estimation" The Int. Jour. for Comp. And Mat. in Elec. and Electronic Eng. Vol. 19 pp.48-69, 2000